NEAR-INFRARED ASTROMETRY: PROGRESS AND PROSPECTS at USNO

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TALK OUTLINE

- Brief history of IR sky surveys/astrometry
- Why these wavelengths are important
- November 1997
- USNO near-IR astrometry program
- Next generation detectors/cameras
- Some future DoD applications
Wavelength Nomenclature

- **Optical**: 0.34 – 0.9 µm  
  (Sun: 5800K → 0.5 µm)
- **Near-IR**: 1.0, 1.25, 1.65, 2.2, 3.5 µm  
  (Sub-stellar, exhaust 1300K → 2.2 µm)
- **Mid-IR**: 5, 10, 20 µm  
  (Planets, sats, etc 300K → 10 µm)
- **Far-IR**: 20+, 100 µm, 200 µm, sub-mm  
  (cold celestial objects 30K → 100 µm)
The Near-Infrared
The Two Micron Sky Survey

- Neugebauer & Leighton (1969)
- 62-inch telescope
- Monolithic detector
- 70% sky coverage
- 5700 objects (5000 point sources)
- Positions to a few arcsec
2MASS: Two Micron All Sky Survey

- Observations obtained during 1997-2001
- Two 1.3-m telescopes in N/S hemispheres
- 256x256 HgCdTe
- 100% sky coverage for |b| > 10 deg
- 300M objects (1M galaxies)
- S/N = 10 limiting mags: J, H, K_s = 15.8, 15.1, 14.3
- Astrometric σ ~ 100-130 mas (70 mas best)

(Monet, Stone, Zacharias @ USNO and others)
AFCRL IR Survey

- Walker and Price (1975)
- Series of rocket flights
- 90% sky coverage
- 2000 sources @ 4 μm, 11 μm, & 27 μm
- Astrometric σ ~ 1300 mas
IRAS: Infrared Astronomical Satellite

- 0.6-m aperture satellite – Jan 1983 launch
- All-sky
- 12 μm, 25μm, 60 μm, & 100 μm
- 350,000 sources (250,000 point sources)
- Astrometric σ ~ 2000 mas
November 1997 (I): 5th Astrometry Forum

- IRCAM – 256x256 HgCdTe test system @ NOFS 1.55-m telescope-operational 1995
- Can you operate 1-2 µm system on non-IR optimized telescope? – Yes
- Astrometric testing results – σ ~ 13 mas
November 1997 (II): 5th Astrometry Forum

- IRCAM only test system – small FOV, marginal pixelization, residual images, etc
- Anticipated new 1024x1024 InSb devices (USNO/NOAO sponsored) in 1998 (science grade delivered 2000)
- Anticipated new camera system for InSb (ASTROCAM) in 1998 (delivered 1999)
# IRCAM vs. ASTROCAM

<table>
<thead>
<tr>
<th></th>
<th>IRCAM</th>
<th>ASTROCAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>HgCdTe</td>
<td>InSb</td>
</tr>
<tr>
<td>Format</td>
<td>256x256</td>
<td>1024x1024</td>
</tr>
<tr>
<td>Pix Pitch</td>
<td>40 μm</td>
<td>27 μm</td>
</tr>
<tr>
<td>Pixelization</td>
<td>0.54 arcsec/pix</td>
<td>0.365 arcsec/pix</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.2 – 2.2 μm</td>
<td>1.0 – 3.5 μm</td>
</tr>
<tr>
<td>Q.E.</td>
<td>20-60%</td>
<td>90%</td>
</tr>
<tr>
<td>Charge Capacity</td>
<td>200K e⁻</td>
<td>400K e⁻</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>Rockwell/UCLA</td>
<td>Raytheon/MKI</td>
</tr>
</tbody>
</table>
Near-IR Astrometry Program

- Began September 2000 w/ 40 objects
- 22 L dwarfs (1300 - 2400K) (H-band)
- 18 T dwarfs (700 – 1300K) (J-band)
- From 2MASS and SDSS
- Today program expanded to ~ 70 objects
- Program delivers both science & astrometric testing
- Preliminary results in May 2004 Astron. J.
Questions & Reminder

- How well can you do small angle near-IR astrometry with a camera specifically designed for this purpose?
- Long-term stability - $\sqrt{n}$ statistics
- $\sigma$ of a single measurement of unit weight
- The near-IR sky is much different than the optical!
Nov 2002: $\sigma=4.31$ mas
Nights = 24
$\Delta T = 1.72$ yr

Sep 2005: $\sigma=2.22$ mas
Nights = 56
$\Delta T = 4.37$ yr
2M2101+17 field (10m exp)
ΔT = 5.05 yr, 294 frames
Seeing 1.0–2.2 FWHM
2M0727+17 field (8m exp)
ΔT = 5.18 yr, 144 frames
Seeing 0.9–2.8 FWHM
Numbers to remember

- Parallax accuracy demonstrated to <1 mas (<0.8 mas)
- Proper motion accuracy demonstrated to < 0.7 mas/yr
- Mean $\sigma$ of single observation $\sim$ 3 mas in each coordinate $\rightarrow$ $\sim$5 mas total error
- 5 mas @ GEO $\rightarrow$ $\sim$ 1-meter
FUTURE

- Near-IR array detectors
- Imaging cameras
- Telescopes
- Space Situational Awareness (SSA)/Space Object Identification (SOI) Projects
ORION: Next Generation InSb Detector

- USNO/NOAO/NASA-Ames collaboration at Raytheon
- 2048x2048 2-side buttable array → effectively 4096x4096 array
- Development project 2001-2006
- Science grade devices are available now
- 0.25 arcsec pixelization → 292 arcmin² FOV (IRCAM 5 arcmin², ASTROCAM 39 arcmin²)
Mid-IR Arrays

- Si:As (5 – 26 µm) 256x256 now available
  1024x1024 within 2-3 years

- Si:Sb (14 -38 µm) 128x128 now available
  256x256 within 2-3 years
Next Generation Near-IR Camera

- Is a camera for 2x2 ORION mosaic feasible?
- USNO-commissioned MKI concept design study for the DCT/Lowell 4.2-m telescope
- Answer: Yes. Optics, Readout Electronics, Filter Size, etc are not issues
- But weight 2500-3000+ lbs → bigger telescope platform
Next Generation Telescope

- DCT still possibility
- A new 3.5-m telescope to replace the 1.55-m in existing facility?
- EOS Technologies Feasibility Study (2005) says YES
- IR-optimized: 0.34 – 20 µm observations
- Total cost of new 3.5-m telescope + 2x2 ORION mosaic system ~ $15M
SSA Capabilities of an IR 3.5-m Telescope

- Astrometric Sky Surveys: Near- and mid-IR
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- Deep GEO Belt: to $d < 10$ cm every night
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- Extreme SOI: optical + near-IR + mid-IR
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- Extreme SOI: optical + near-IR + mid-IR
- Adaptive Optics: 50-100 mas PSF – faint objects at lethal distances at GEO
Block II, IIA, & IIR – Opt + IR

GPS Spectral Energy Distributions

<table>
<thead>
<tr>
<th>Wavelength (μm)</th>
<th>Log Flux (Jansky)</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>-1</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
<td>2.5</td>
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</table>

- Block II (sv1m and sv1n)
- Block IIA (sv2n)
- Block IIR (sv4n and sv5n)

[d = 20K km, r = 1.0 AU, φ = 140 deg]

[Block II, IIA data corrected to mean age of Block IIR data]
Notional Extreme SOI

- Optical $\rightarrow$ spectra $\rightarrow$ materials
  (Monet et al. @ USNO)
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- Near-IR Flux $\rightarrow$ reflectivity $(a) \times$ Size
  (Vrba et al. @ USNO)
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- **Optical** → spectra → materials  
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- **Near-IR Flux** → reflectivity \((a)\) x Size  
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- **Mid-IR Flux** → \(T \times \text{emissivity } (\varepsilon) \times \text{Size}\)  
  (Witte et al. @ AEOS)
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- \( f_{\lambda} [a + \varepsilon \approx 1] \)
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- \(f_\lambda [a + \varepsilon \approx 1]\)
- → materials, \(T\), size \((d << 10 \text{ cm @ GEO})\)
Spectra of stars (smears) and Satellites (points + spectra)